The Use of *In-situ* X-ray Diffraction, Elastic Light Scattering, and Resistance Analysis Techniques for Evaluation of Copper Diffusion Barriers in Blanket Films and Damascene Structures

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Introduction: Copper diffusion barriers in current CMOS technologies serve a variety of functions. The barriers must prevent diffusion of Cu into the dielectric material, be as conformal as possible, adhere to both Cu and the dielectric material, form an interface with Cu so as to limit surface diffusion, have a relatively low resistivity, and be as thin as possible. We have explored Cu diffusion barriers using three different *in-situ* techniques.

Methods and Materials: Four different magnetron-sputtered barriers (Ta, Ti_7W_{93}, $Ta_{36}Si_{12}N_{52}$, TiN) in the thickness range 20-24 nm, were placed between Cu and Si in blanket films and in damascene structures. The damascene features consisted of SiO_2 trenches with Si bottoms, 0.6 microns deep, 0.23-0.62 microns wide (aspect ratios 0.97 to 2.6), and 5.1-80 microns long. *In-situ* anneals consisted of temperature ramps at 3 degrees C/sec from 100 to 1000 C in nitrogen. Simultaneous diffraction, HeNe laser light scattering at two length scales (0.5 and 5 microns), and four-point probe resistance measurements were recorded during the anneals. Barrier failure temperatures were determined by the average of the temperatures at which the Cu(111) diffraction peak disappeared and the Cu silicide peak appeared. For comparison, they were also determined by changes in the scattered laser light intensity.

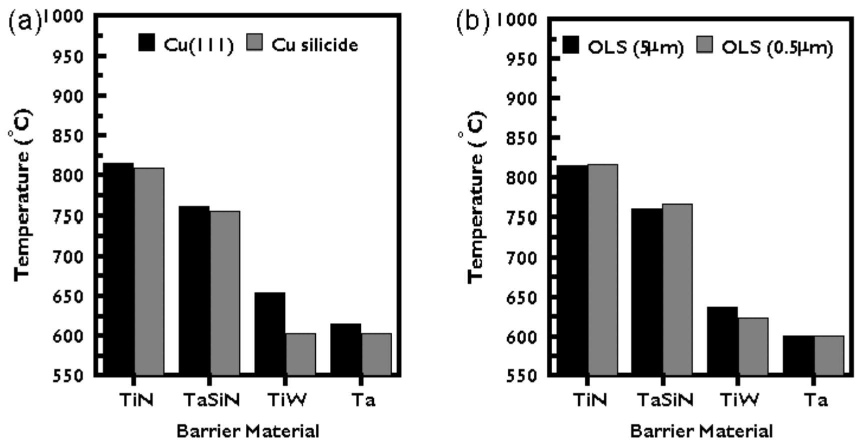

Figure 1 Barrier failure temperatures in patterned damascene structures of aspect ratio 2.6 comparing Ta, Ti_7W_{93}, $Ta_{36}Si_{12}N_{52}$, and TiN copper diffusion barriers using *in-situ* x-ray diffraction analysis (a) and elastic light scattering at two different length

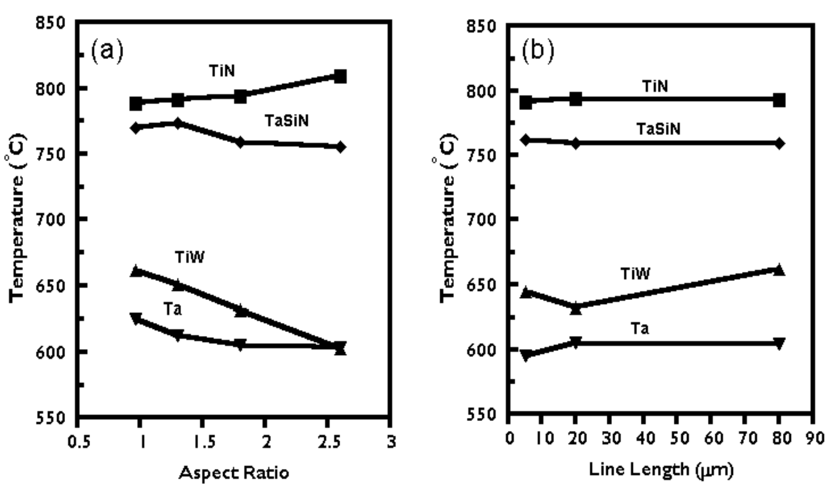

Figure 2 Barrier failure temperatures comparing Ta, Ti_7W_{93}, $Ta_{36}Si_{12}N_{52}$, and TiN copper diffusion barriers in patterned damascene structures as a function of aspect ratio (a) and line length (b).

Results: There was good agreement between the diffraction and light scattering techniques in terms of barrier failure temperatures. Figure 1a compares the barrier failure temperatures in 2.6-aspect-ratio damascene features using the x-ray diffraction technique. In Figure 1b the same damascene features are analyzed with elastic light scattering. Figure 2a compares the failure temperatures of the barriers in damascene features of varying aspect ratio using the diffraction results. In all cases, except for TiN, the barrier failure temperatures decrease with increasing aspect ratio. Comparing the barrier failure temperatures as a function of line length with line width held constant at 0.33 microns (Figure 2b), no distinct trend is seen.

Conclusions: The order of increasing effectiveness of the barriers was Ta< Ti_7W_{93}< $Ta_{36}Si_{12}N_{52}$< TiN . The data suggest that at higher aspect ratios the lower failure temperatures are due to less barrier coverage at the bottom of the damascene feature.